Functionality Inspection of Interconnected Fire Protection Systems

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Functionality Inspection of Interconnected Fire Protection Systems

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ABSTRACT

After 2004, where the Danish buildings code changed from prescriptive to performance based requirements for fire safety, the number of installed fire protections systems has increased with about 30 percent. Furthermore, fire safety strategies often call for combinations of active fire protection systems, such as a smoke detection system, sprinkler system, warning system and fire ventilation system. However, only smoke detections systems and sprinkler systems require inspection from an independent accredited company, whereas the other systems' functionality is entirely up to the professionals that install them and the owner's maintenance schedule, both of which do not require any supervision from the authorities. Herein, 12 complex buildings, in which all fire protections systems were inspected by an independent accredited company, were studied to see whether or not the buildings adhere to the fire safety design in their operational phase. The results showed that the functionality of the interconnected fire protection systems was not as designed in the performance-based analysis. Furthermore, due to the lack of this functionality the fire safety level is not at high as the authorities' demand, something which could have fatal consequences in the event of a fire.

INTRODUCTION

Active fire protection systems are all considered as one specific entity (such as sprinkler system, alarm system, and ventilation system), and designed after their own standards and guidelines. In Denmark, only two of the systems require inspection and approval from the authorities before the building is approved for use. The problem identified and discussed herein is that all of the fire protections systems in the building are not considered as one interconnected system, and therefore the interconnected fire protections systems are not inspected for combined functionality. On the contrary, the individual fire protection systems are tested without any reference to how they should interact with other systems in the case of a fire.

On the other hand, the interconnected fire protection systems are considered as one entity in the performance-based design that is undertaken by the fire safety engineer and presented in the fire strategy report that has to be approved by the authorities having jurisdiction before the building can be commissioned. As such, the appropriate fire safety level can only be reached if all the systems work, both by themselves and in interplay with the other systems. This includes going to error mode when such interconnected systems are not receiving the appropriate input signals from the systems they are meant to interact with in an emergency situation. Without such an error mode reported to the controlling system, the operator in the control center at the fire brigade will not receive this error and will thus be unable to fix the cause of the error mode.

In Denmark, the building authority approves the performance-based analysis of the fire safety design. The process include a verification process to ensure that the standards that the fire engineer use for the fire safety design are the appropriate ones to reach the expected fire safety level in the building. The legislation is intended to demand a certain safety level [1], but these demands are not explicitly quantified in the Building Regulations (BR10) [2]. The detailed requirements are provided in the accompanying performance-based guidance document [3]. The legislation has one demand for the functionality of the fire safety system, which is that the systems should function in the entire lifetime of the building. However, there are no demands for any specific documentation for how the occupants or building owner should ensure this.

In the operational phase, the fire brigade is allowed to make fire inspections in buildings covered by the Order on Operational Requirements, which is published by the Ministry of Defense and provides all the maintenance and inspection requirements for passive and active fire protection solutions [4]. Buildings that are constructed after performance-based analysis, which normally have several active fire protection systems installed, do not automatically require a fire inspection. Rather, an inspection will only take place if some part of or the entire building's occupancy type is covered by the operational regulations.

Figure 1 provides a simplified overview of how the responsibility of the fire safety of a building changes from the design and construction phase to the operational phase.

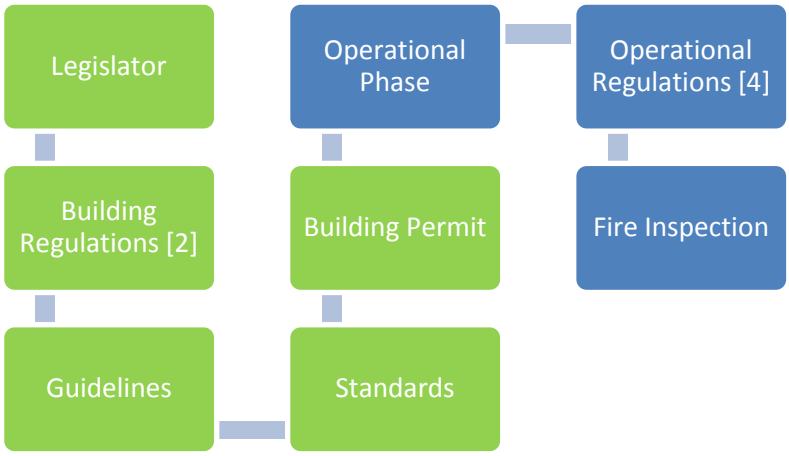

Figure 1 Overview of the Danish Fire Safety Legislation System. Legislation for buildings is shown in green, whereas legislations for the fire brigade are shown in blue.

Smoke Detection System Statistics

Statistics from Aalborg for the period from 1996 to 2012 show that there was a steady increase in the number of automatic fire alarm (ABA) systems in the municipality, as seen in Figure 2 [5]. These systems are installed after a guideline and inspected by an accredited inspection company every year [6].

In 2012, the Aalborg Fire Brigade control center received 308 alarms from automatic fire alarm (ABA) systems. The causes that lead to activation of the alarm system were registered in the Aalborg Fire Brigade internal system, and are shown graphically in Fig. 3 [5]. Only in two of the ten fire cases had fire spread beyond the ignition object, and only those two fires needed action from firefighters to extinguish the fire. It can also be seen that it was mainly operational and behavioral actions that caused the activation of the smoke detections system.

227 of the recorded alarms were due to misbehavior, whereas the remaining 71 alarms were categorized as unknown. These were further subdivided into 59 alarms without known cause and 12 alarms caused by pressure drop in the sprinkler system without sprinkler activation. It should be noted that there is no tradition for further examination of the failures.

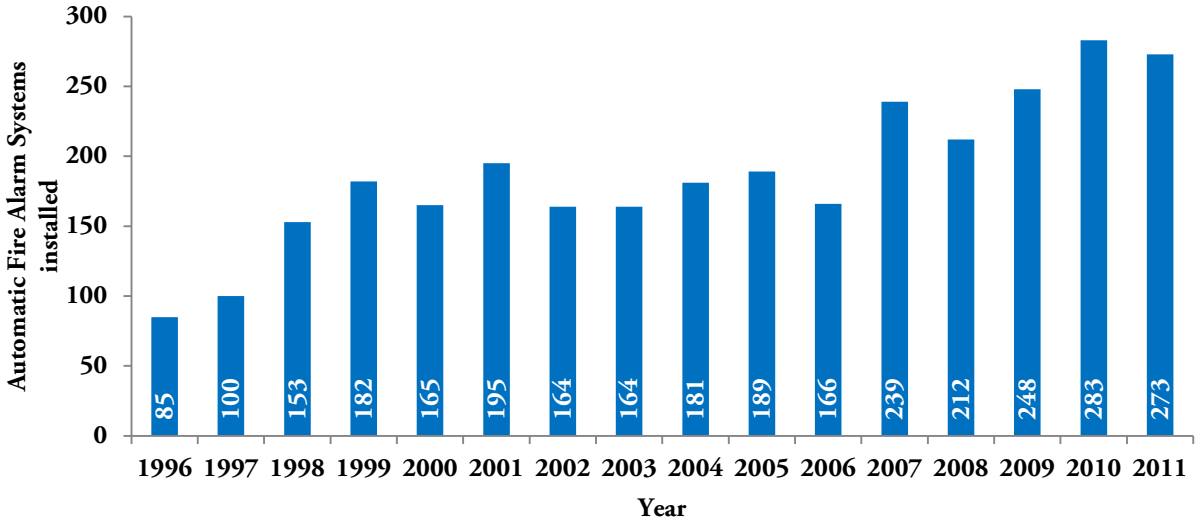

Figure 2 The number of automatic fire alarm systems in Aalborg municipality versus calendar year [5].

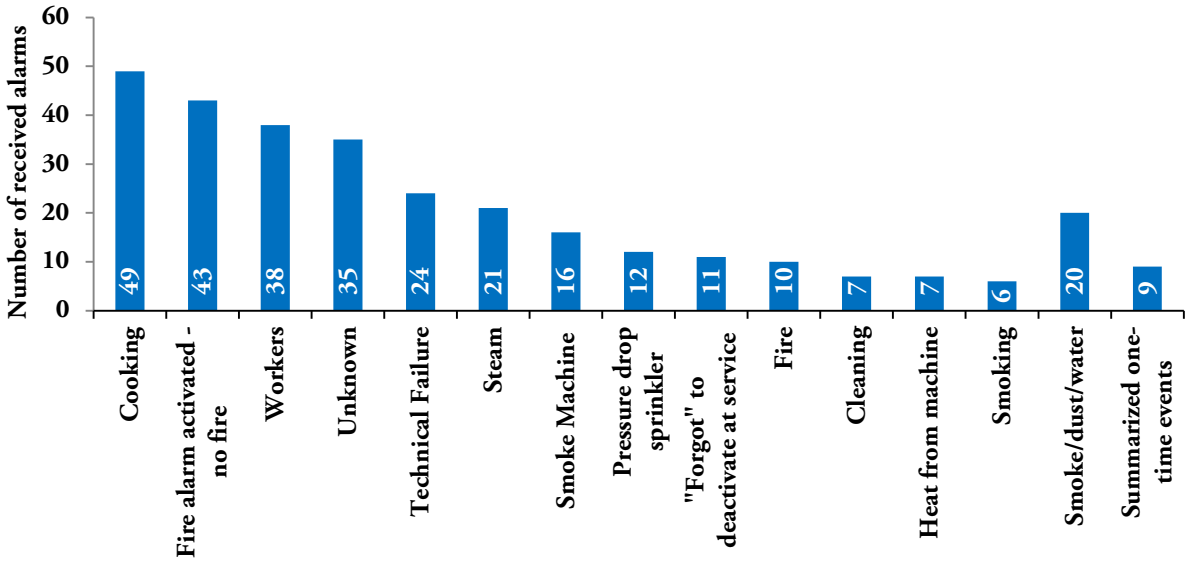

Figure 3 Causes for the automatic fire alarms received by the Aalborg Fire Brigade in 2012.

The Danish Institute for Fire and Safety Technology (DBI) publishes the guidelines that are used for the majority of fire protection systems in Denmark. DBI is also one of the two accredited inspection companies for fire protection systems, and they publish an annual report that shows statistics from all their inspections [7]. The result for 2011 (published in 2012) report a reliability of 99.1% for smoke detection systems, which is rather remarkable given that the Aalborg Fire Brigade statistics [5] shows there only have been fires in 3.2% of the cases where the smoke detections system had been activated. As such, there is a discrepancy between reliability and performance that calls for further investigation.

The Aalborg statistics from 2012 [5] compares well with those from Vineland, New Jersey were statistics shows there only was a real fire in only 3 % of the causes were the Fire

Brigade was called out by activated smoke detection [8]. In the same study, it was documented that 70% of the 244 calls from smoke detections system in three high rise buildings were false alarms. The false alarms could be placed in 4 categories: i) Improper operation, ii) Building workers started without notifications, iii) System malfunctions and iv) Damage on the system. They succeeded in bringing the false alarms down with 50% by focusing on training/education, improved procedures and communication, and by investigating causes for false alarms [8]. As a final comparison, a Swedish study of the alarm failure problem concluded that there is only a fire in 6.4% of the cases where fire protections systems are activated [9].

METHOD

The current study investigated the functionality of interconnected fire protections systems in 12 large buildings located across Denmark. In all off the cases, an inspection was required in the building permit, for all of the fire protections systems. The data in the cases are from accredited inspections firm, who agreed to provide these inspection reports from performance based building for the project. The inspected buildings were as shown in Table 1.

Table 1 Overview of the different buildings studied herein.

Case #	Use	Area [m^2] total/detached	Occupancy Category BR10 [2]	Inspection company and the respective journal nr.	Installed fire protection system*
1	Shopping center	18,500/3,000	1, 2 & 3	RMG-10357-3-2012	ABA, AVS, ABV-27, AVA-24.
2	Shopping center	21,500/3,500	1, 2 & 3	DBI-IF00026/IG00015	AVS, ABV-27, AVA-024.
3	Shopping center	25,000/-	1, 2 & 3	RMG-29.10-012/PBN	AVS, ABV-27, AVA-24.
4	School	4,500/-	2 & 3	BCA note/DBI-B10406	AVS, ABV-27, AVA-24.
5	Sports complex	34,000/7,500	3	Inspection date filibustered	AVS, ABV-27, AVA-24.
6	Shopping center	36,000	2 & 3	RMG-16100-15-2010	AVS, ABV-27, AVA-24.
7	School	2,000	2 & 3	RMG-16744	ABV-27.
8	Water amusement park	9,000	3	RMG-15690	ABA, AVS, ABV-27, AVA-24.
9	Pressurized stairways High-rise building	-		RMG-17987	ABA; DS/EN 12101-6.
10	Pressurized stairways in Car park in basement/hotel.	-		RMG-18181	ABA, DS/EN 12101-6.
11	Nightclub	-	3	RMG-12837-15-2012	ABV-27.
12	Supermarket	7,250	3	RMG-18044-2012	ABA, AVS, ABV-27, AVA-024.

*ABA = Automatic Smoke Detection System; AVS = Automatic Sprinkler System; ABV = Automatic Fire Ventilation System, 27 [10] or 027 [11] describes the standard the system is referring to; AVA = Automatic Warning System, 24 [12] or 024 [13] describes the standard the system is referring to.

Case #4 – School Building

For a building that is designed using performance-based design, the failures are registered when the fire systems were inspected after the buildings were reported as finished. The case, a high school with a floor area of approximately 4,500 m^2, was taken into use in the autumn of 2012. Table 2 shows the connection between the fire systems, whereas Figure 4 details the failures registered in this building case. It is seen that the interdependency of the systems is not as desired due to an abundance of errors.

Table 2 The interconnectivity of the systems in Case #4 – School Building.

Activation of	Mechanical smoke ventilation	Warning systems (Voice)	Alarm transmission to Fire Brigade	Atrium sprinkler	Fire doors shut automatically upon detection	Elevator goes to ground floor
(ABA) smoke detector	NO	YES	YES	-	YES	YES
Line/flame detector	NO	YES	YES	YES	NO	YES
(AVS) sprinkler	NO	-	NO	PARTIAL	NO	-
(ABV) Smoke ventilation	NO	-	NO	-	NO	-
Fire call press	-	YES	YES	-	NO	YES
Atrium sprinkler	YES	YES	YES	-	NO	-

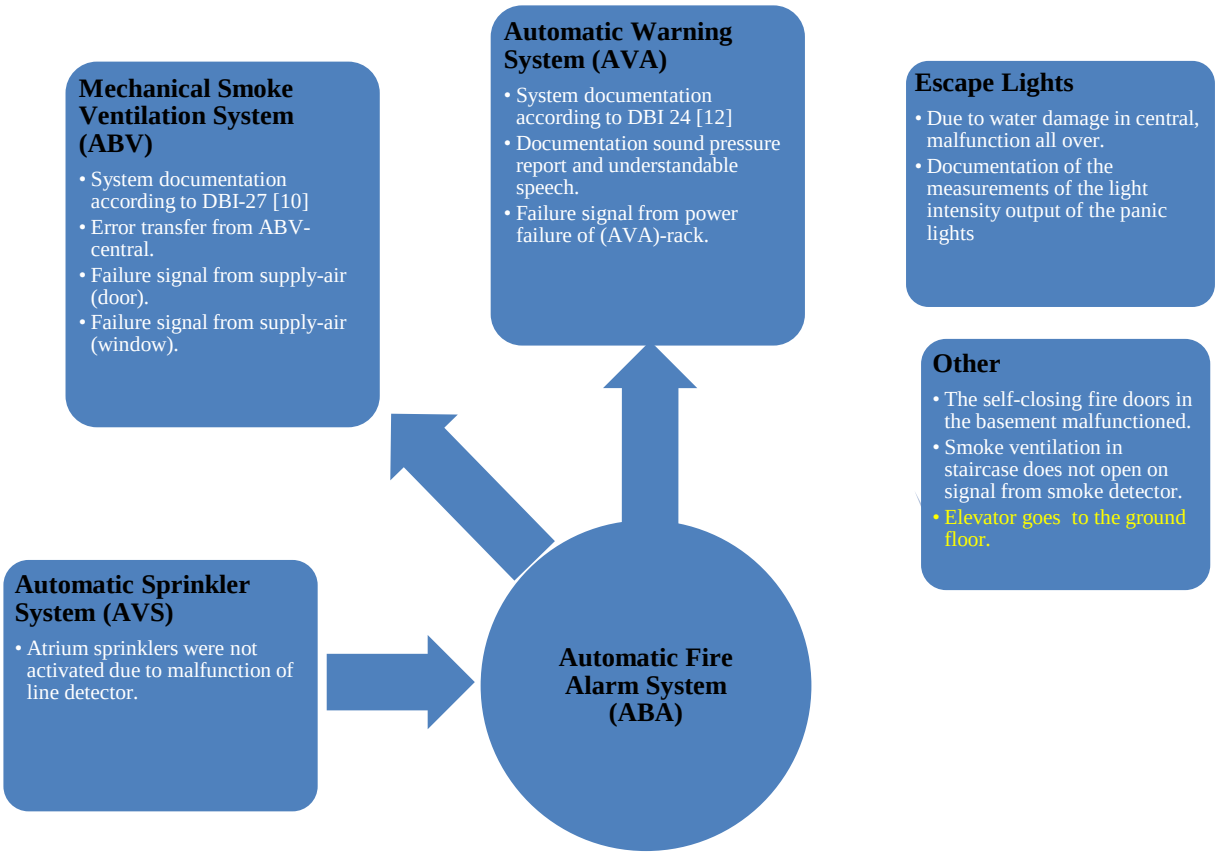

Figure 4 Example of the data collection and failure registration in Building Case #4. The white text represents activity with unwanted functionality, whereas the yellow text represents activity with wanted functionality.

Categorization of Failures

The categorization of the observed failures was performed according to the required protocol as provided in the guidelines by The Danish Institute for Fire and Safety Technology [14]. This method is used by accredited inspection companies during their inspections. During the first inspection, up to two C-failures are allowed. Systems with a single occurrence of an A- or B-failure cannot be approved. The defects are categorized as follows:

A: Significant deficiencies that can result in a non-functional system.
B: Deficiencies that can result in a situation where parts of the system will be non-functional.
C: Minor deficiencies, which could ultimately result in a situation where the system or parts thereof will not provide the expected protection.
D: Correct functionality

Using this method, it was possible to categorize the systems as 'Approved', 'Conditionally Approved' and 'Not Approved'. Conditionally approved means that the found failure should be fixed and the fire system re-inspected within 3 months.

RESULT AND DISCUSSION

Observed Failures in the Inspection Cases

Figure 5 provides an overview of the categorization of the observed failures of the automatic smoke ventilation system for the 12 inspection cases in the current study.

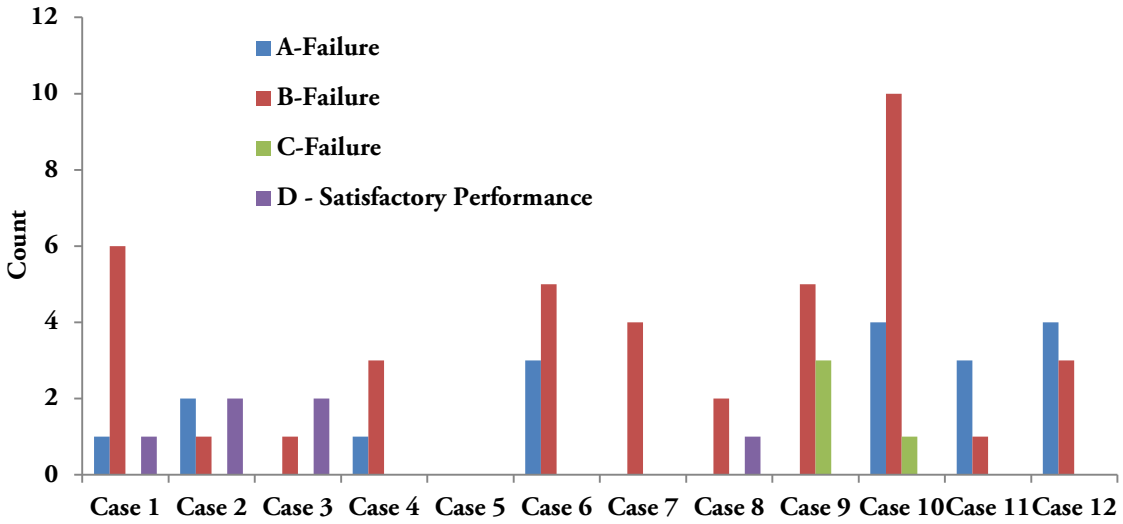

Figure 5 Failure categorization (A-, B- or C-failure or D – Satisfactory Performance) of the automatic smoke ventilation system for all cases in this study. Note that some of the buildings did not have such a system.

In 64% of the inspected buildings, there was an A-failure, and in all of the inspected buildings B-failures were recorded (Case #5 is excluded from this). Actually, in 72% of the inspection cases more than one B-failure was registered. Only a few C-failures were recorded during the inspections, something which may come as a result of the large number of A- and B-failures. It is perceived that, as a result of the abundance of these graver errors, the inspector did not bother to concentrate on the minor details, as it was clear that further work on the systems were needed for approval. It is concerning that the capacity of the smoke ventilation systems were found to be insufficient (as compared to the design capacity from

the fire safety strategies) in 40% of the investigated cases. In one case, only 33 % of the needed capacity, as calculated by the fire safety engineer, and this would quite clearly have a significant effect on the fire safety level.

In 83% of the investigated systems, there was no transmission signal from errors arising from the doors or windows that serve as openings for supply air for the smoke ventilation to function according to design. If the right amount of supply air is not brought into the building, the smoke venting capacity may not be sufficient, or worse yet, the smoke flow direction may be reversed.

In 89% of the investigated cases there was no signal from errors that occurred in the smoke ventilation system central. The consequence of this would be that the maintenance personnel need to detect the error manually during inspections according to the maintenance protocol. As a result, the system is significantly less likely to function as prescribed during an emergency event.

Figure 6 provides an overview of the categorization of the observed failures of the automatic smoke ventilation system for the 12 inspection cases. The total absence of C-failures is noteworthy, as it is completely against common reliability theory.

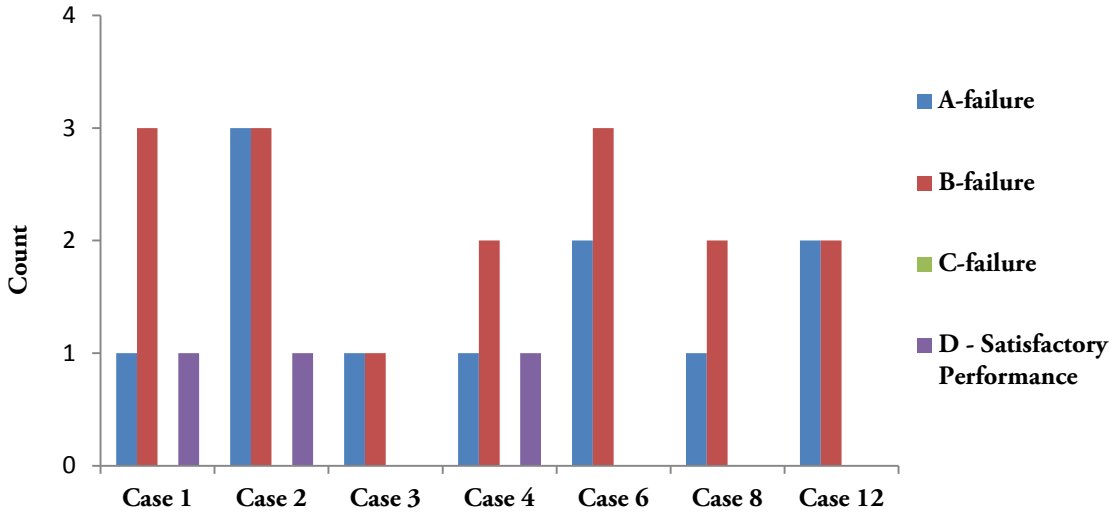

Figure 6 Failure categorization of the automatic warning systems in this study. Note that some of the buildings did not have such a system.

Table 3 presents the total count and score for each of the failure categories for both the smoke ventilation system and the warning system for all the inspections.

Table 3 Total score for A-, B- and C-failures for both smoke ventilation and warning system for all cases.

	Type of Failure			
	A	B	C	D (Satisfactory Performance)
Total failure count for the smoke ventilations system	20	39	4	6
Total failure count for the warning systems	11	16	0	3

Figure 7 is a radar-diagram showing A-, B-, and C-failures along with D – Satisfactory Performance. Clearly, A- and B-failures are the ones with strongest representation, whereas

there is a low population of C-failures, which is probably due to the large count of A- and B-failures, as discussed above. The figure also shows that there are significantly more failures for the smoke ventilations systems (ABV) than for the warning systems (AVA). This is in line with results presented by Klote and Milke, who reported that ventilation systems often can have a low reliability due to the fact that consist of a large number of components [15].

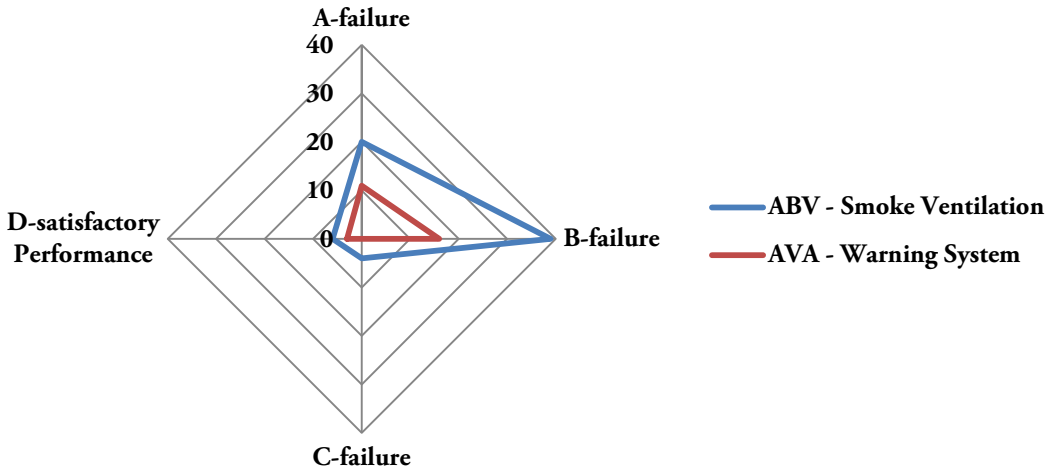

Figure 7 Radar-diagram showing A-, B-, and C-failures, as well as Satisfactory Performance (D), for smoke ventilation and warning systems.

Overall Results of the Investigated Cases

Figure 8 shows that the functionality of the interconnected fire protections systems is not satisfactory. That is, the functionality is not as designed in the performance-based analysis, which means that the fire safety does not match the one demanded by the authorities having jurisdiction. Such a reduction in the safety can obviously lead to fatal consequences in the case of a fire. Given that the smoke detection system and sprinkler system is under accredited inspections, the problems are transferred to the smoke ventilation system and warning system, and apparently there are challenges associated with installing these systems according to the guidelines/standards.

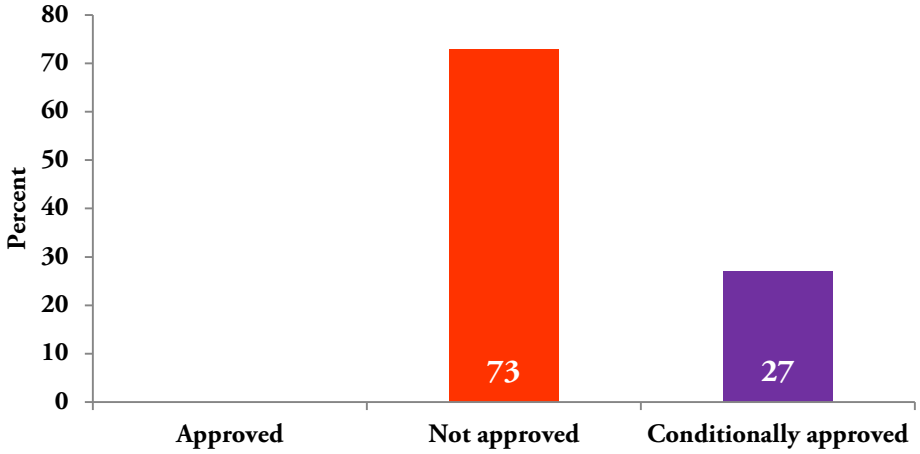

Figure 8 Overall results for all the interconnected fire protection system, categorized according to the required protocol for an accredited inspection firm.

The results presented in percent are showing a trend, but due to the small investigated population, this could not be considered as well documented as individual occurrences can dominate the total outcome.

Results for the Smoke Ventilation Systems

In 100% of the investigated cases there was not the system documentation as demanded in the guideline [10, 11]. Only 60 % of the investigated cases had the needed flow capacity, and the fire resistance of the fan was only documented as sufficient in 40% of the cases. No error was transferred to the controlling system in 83% of the cases for failures associated with the supply air (doors/windows). In 89% of the cases, an error with origin in the ABV-central was not transferred to the controlling system (ABA).

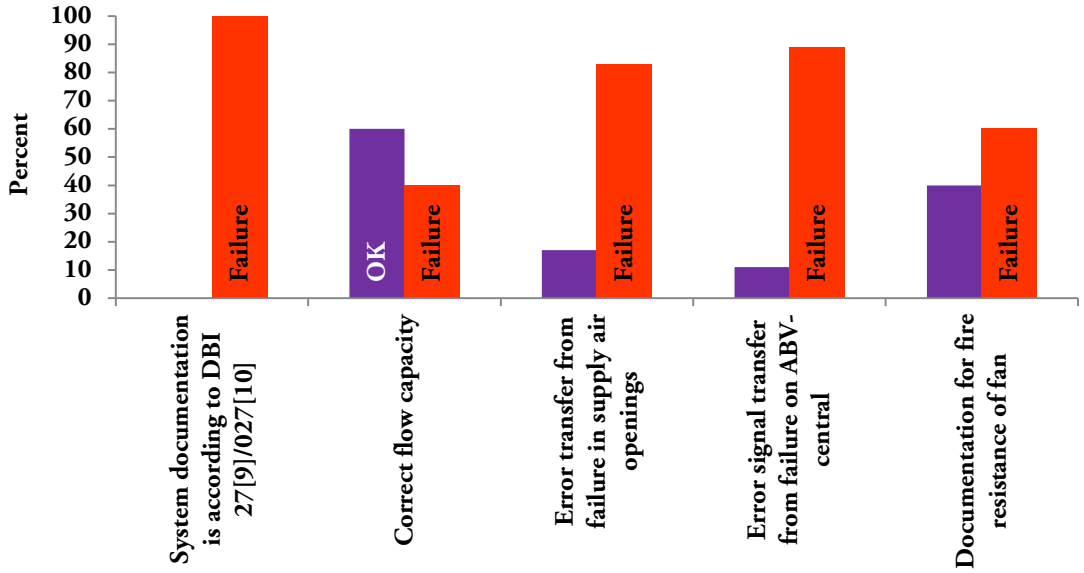

Figure 7 Results for the system failures that were found for the smoke ventilation systems. The OK is only labeled once, but applies to the other columns with the same color.

Results for the Warning Systems

None of the investigated cases had system documentation and drawings that verified that the interconnected system has a built-in redundancy. This is to ensure that if one system were to fail, the other will still be able to function. Even though the requirement is that all systems are composed of certificated components, this was not always the case, as cases of use of non-standard parts were detected.

The error transfer to the controlling system failed in 85 % of the investigated cases. Another significant problem occurred in all of the cases, which was that the noise associated with the operation of the mechanical smoke ventilation system was so loud that it was impossible to hear the sounding from the warning system in that zone.

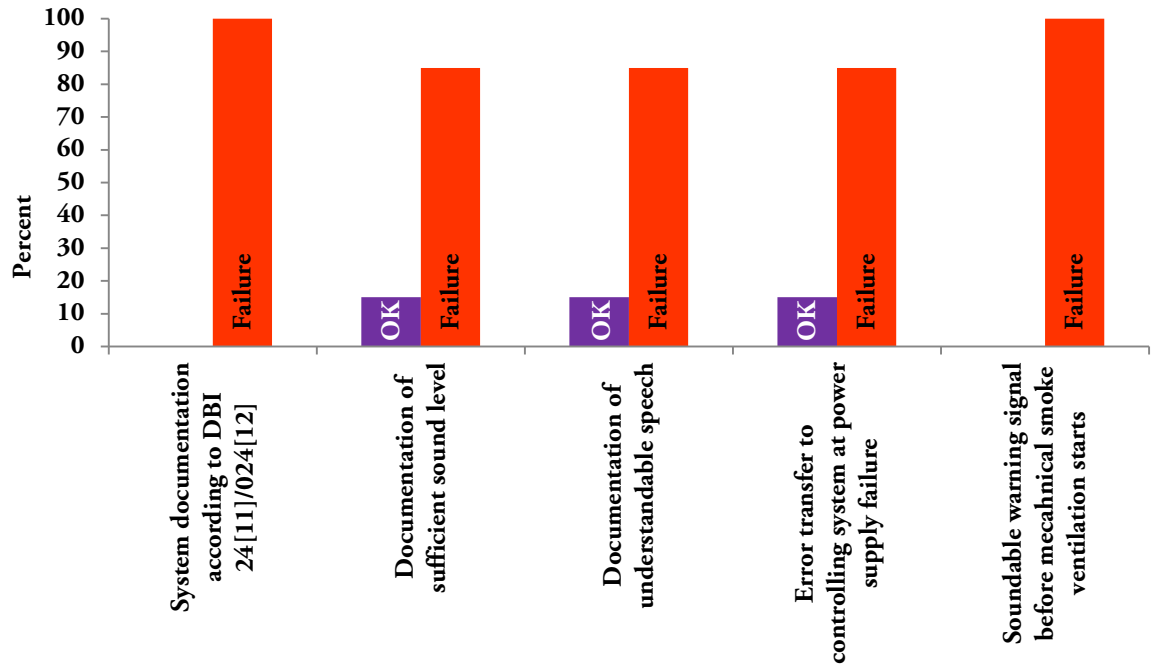

Figure 8 Results for system failures found for warning systems.

Figure 9 shows the overall outcome of the study (left) and the inspection statistics from The Danish Institute for Fire and Safety Technology. Although the system types are not the same, the discrepancy of the results calls for a different and more thorough inspection in order to create appropriate statistics, as there is a difference between 'working' and 'working according to the fire safety strategy'. That is, simply starting the system for a short period does not account for a proper inspection, as all components and system interdependencies have to be check for appropriate performance and dimensioning. The full details of all the observations in each of the cases are presented in a report by Kærup [17].

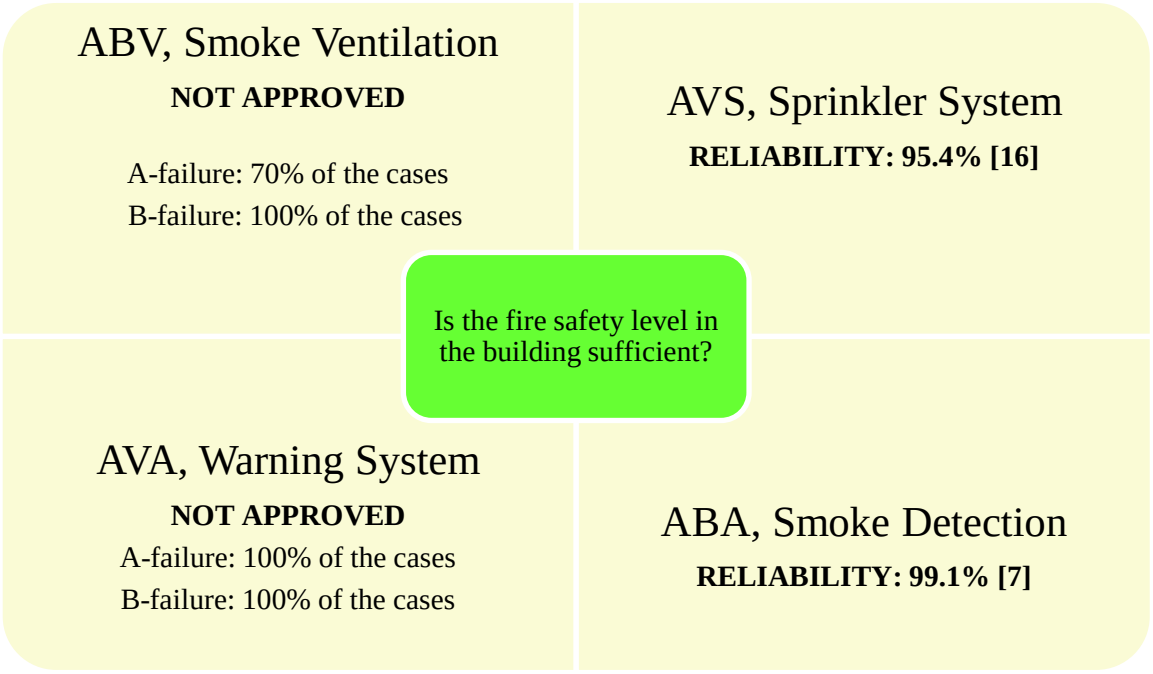

Figure 9 The overall results for each fire protection system in the building.

CONCLUSIONS

The results from the series of in-depth system inspections in buildings with interconnected fire safety systems presented herein are quite disconcerting. The inspections revealed that, even though all the systems that are mentioned in the fire strategy report are installed and are operable, their interdependency and their functionality are often not according to the prescribed design. This means that a lot of effort and money is put into the fire safety design in vain. Furthermore, as there are no inspection procedures or guidelines that require an inspection of the overall functionality of the interconnected fire protections systems, it appears to have a low priority, as it is then perceived to only have a cost associated with the inspection and no visible gain. The lack of inspections in the construction phase, upon commissioning and in the operational phase leads to a lack of information about the fire protection systems, something which in turn makes it close to impossible for the maintenance personnel to secure the correct interconnectivity of these systems.

Obviously, there is a challenge ahead when published reports show that the reliability of the certain automatic alarm systems is as high as 99.1%, whereas the statistics from the Aalborg Fire Brigade show that only approximately 3% of alarms were due to fire. The statistics show that approximately 80% of the reasons for the detection of the smoke detection system are due to attitude behavior, where instructions, training and education is one way of reducing the reasons for false alarms. In Denmark, fines have also been introduced for false alarms, both as an incentive to work towards fewer false alarms, but also to recover some of the costs associated with this unnecessary use of the fire brigades. It is emphasized that this is not a critique of the reports published by DBI, but rather a call for a change in the inspection requirements, so that the reliability of the interconnected systems can be as high as for the individual systems.

The results also show that we need to consider all the interconnected fire protection systems as one (1) system that has a huge influence on the fire safety level in the building. Still, each different fire protection system should be inspected according to the relevant standard/guideline. In addition, there should also be undertaken an overall inspection that focus on the functionality of the systems, as described by the fire safety engineer in the fire strategy report.

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